Cognitive Radio Network – A New Paradigm in Wireless Communication

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ABSTRACT
In wireless Communication system, Radio Spectrum is the most valuable and limited resource. Due to traditional fixed spectrum allocation policy, there is a problem of spectrum under-utilization in licensed band whereas an unlicensed band is getting overcrowded. A new device called Cognitive Radio (CR) is introduced which allows unlicensed users to access licensed spectrum, without interfering with the operation of licensed user. Cognitive Radio follows Dynamic Spectrum Access Policy which makes it more vulnerable to the various attacks compared to traditional policy. An attacker can disrupt the basic functions of a Cognitive Radio Network (CRN) and cause harmful interference to the licensed user. Therefore security of CR is also a major concern. This paper provides a brief overview on operation, principles, architecture and security of Cognitive Radio. Finally, persistently unsolved challenges are highlighted.

General Terms
Cognitive Radio architecture, dynamic spectrum allocation, security, cognitive cycle

Keywords
Cognitive Radio network, functions, Spectrum sensing, Attack, open challenges

1. INTRODUCTION
RADIO frequency spectrum is the heart of wireless communication system and its efficacious usage is of uttermost significance. The distribution of this valuable and limited radio frequency resource, as decided by the Federal Communication Commission (FCC), is based on traditional fixed spectrum access policy [1]. This traditional scheme for spectrum assignment divides the frequencies into licensed and unlicensed band. In Licensed frequency spectrum, exclusive right is provided to a designated user or wireless service provider and other users are not allowed to access this band, even though it is free at particular time and location. It has been pointed out by the Spectrum Policy Task Force. (SPTF) that some portion of licensed spectrum is heavily utilized whereas some are very less or partially occupied at particular location and time [2]. Measurement were taken between Jan 2004 and Aug 2005 by Shared Spectrum Company (SSC) which shows that on the average only 5.2% of the spectrum between 30MHz and 3GHz is in use at 6 different locations in the U.S.A. The highest value was 13% at New York City and lowest was 1% at the National Radio Astronomy Observatory. All these measurements clearly show that large portion of licensed spectrum remains unutilized. Due to fixed nature of traditional spectrum policy, unlicensed users are prohibited from accessing the spectrum band. This low utilization of frequency spectrum increases the cost of bandwidth and degrades performance of wireless communication systems [3]. Fig. 1 shows that some areas of licensed spectrum are highly used whereas some are very less utilized and can be used by other users.

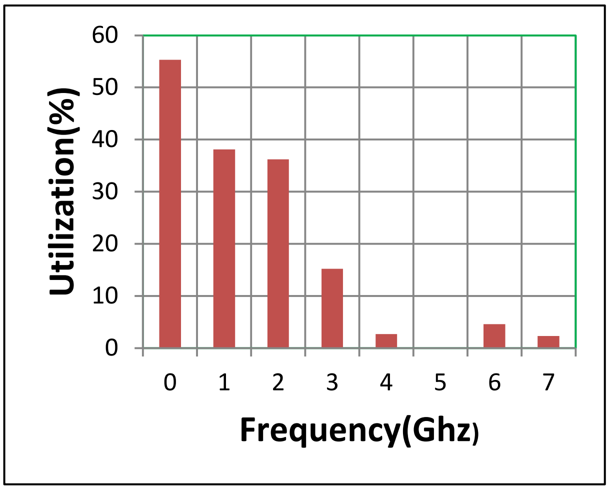

Fig 1: Spectrum Utilization

Unlicensed frequency bands are the portion of spectrum kept aside to access freely by the users. The most widely used unlicensed bands are the 2.4 GHz Industrial, Scientific and Medical (ISM) band, used by IEEE 802.11b/g/n and Bluetooth devices and the 5GHz band Unlicensed National Information Infrastructure (UNII) are used by IEEE 802.11a and European HIPERLAN standard [3].

On the other hand, due to new wireless technologies and services like internet, smartphones, social networking sites, these unlicensed bands are getting overcrowded which leads to a problem called spectrum scarcity. The problem is not the spectrum shortage; it is lack of the technology which can effectively access the spectrum.

This inefficient utilization of licensed spectrum and spectrum shortage problem in unlicensed band forces Federal Communication Commission to modify the existing fixed spectrum allocation scheme. FCC decided to make the spectrum flexible by allowing unlicensed user to access licensed spectrum band when it is idle, without any interference with the licensed user transmission [4].

This new spectrum policy lead to the introduction of a device called COGNITIVE RADIO, which uses Dynamic Spectrum Access (DSA). Software defined radio is the key component and platform for CR in which transmission parameters (frequency of operation, modulation mode, transmission power and protocols) can be coordinated dynamically to satisfy application requirement. This adjustability function is accomplished by software controlled signal processing algorithm. A transreciever is present which carry out all the functions at the physical layer in the software. The reconfigurability offered by SDR technology allows radios to switch functions and operations [10]. Cognitive Radio is called intelligent Radio because of its learning capability i.e. it understand and assumes the surrounding environment and takes actions in the direction of goal. An ideal CR is expected to sense and correct the problems before it takes place using machine learning technology incorporated in cognitive Engine [4].

2. FUNDAMENTAL CONCEPT

A Cognitive radio must have real element of cognition which deals with the way human recognize object in their surrounding environment in addition with the capability of filtering out some stimuli. Two main characteristic of CR

Cognitive Capability: It refers to the ability of the radio technology to capture or sense the information from its Surrounding radio environment [4], [5].

Reconfigurability: It is the capability of adjusting the operating parameters for the transmission in real time without any modification on the hardware components. This capability enables the cognitive radio to adapt easily to the flexible radio environment. Parameters which can be altered are operating frequency, modulation, transmission power, protocols. Thus Cognitive radio can change its transmission parameters according to user requirement on the fly which was not possible with the conventional radios [5]. The main objective of CR is 1) to achieve highly reliable and effective wireless communication system. 2) To improve frequency spectrum utilization. For achieving these objectives, CR senses the spectrum holes or White spaces and performs opportunistic spectrum access as shown in Fig 2.

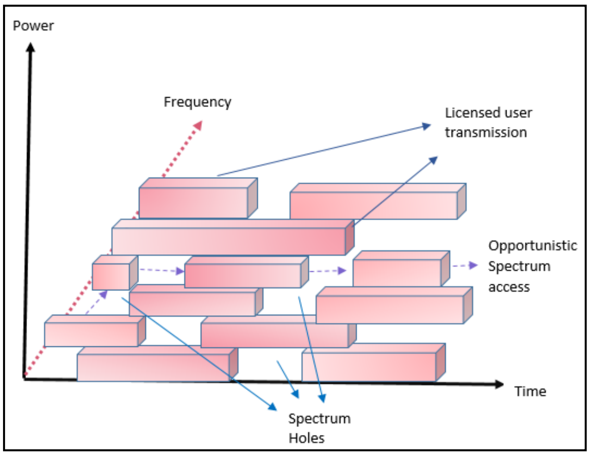

Fig 2: Spectrum Holes

Cognitive Radio is a rising technology, in which unlicensed users analyze the frequency spectrum to transmit the information without causing any interference to the licensed user. This is the fundamental meaning of CR according to many people; defining CR is still an ongoing effort. Different regulatory bodies and people have considered various factors to define cognitive Radio.

The US FCC provided with a confining definition

"*A cognitive Radio is a radio that can change its transmission parameter based on the interaction with the environment in which it operates* [2]"

The definition of Cognitive Radio presented by Joseph Mitola [7] is "*A radio frequency transceiver designed to intelligently detect whether a particular segment of radio spectrum is in use and to jump into and out of temporarily unused spectrum very rapidly without interfering with the transmission of other authorized users. Cognitive radio enables secondary user to sense which portion of spectrum are available, select best available channel, coordinate spectrum access with other users and vacate the channel when a primary user reclaims the spectrum usage rights*"

Another popular definition by Simon Haykin [1]: "*Cognitive radio is an intelligent wireless communication system that is aware of its surrounding environment and uses the methodology of understanding-by-building to learn from the environment and adapt its internal states to statistical variations in the incoming RF stimuli by making corresponding changes in certain operating parameters in real-time, with two primary objectives in mind:*

- *highly reliable communications whenever and wherever needed;*
- *Efficient utilization of the radio spectrum*."

National Telecommunication and Information Administration (NTIA) also provided with a convincing definition, but it does not cover all the features of CR. International Telecommunication (ITU) considered CR capable of effective spectrum usage in mobile radio system. Maximum features are covered in the Joseph Mitola's Definition [7], which is widely accepted.

A table is displayed below which consist of parameters considered by different people while defining CR

Table 1. Definitions of Cognitive Radio

Parameters \ Definer	FCC	Haykin	Mitola	NTIA	ITU-R	IEEE 1900.1
Environment sensing	√	√	√	√	√	√
Autonomous	√	√	√	√	√	√
Transmitter	√	√	√	√	√	√
Receiver		√	√	√	√	√
Awareness			√		√	
Intelligence	√	√	√	√	√	√
Learning Capability		√	√			
Application oriented		√	√	√		
Interference avoidance						
Negotiate waveform			√			

The necessary factors should be seen in the definition of CR [6]

- Sensing the environment
- Building a predictive model of such environment based on previous experiences; and
- Utilizing the sensed stimuli and the predictive model to adapt its transmitting configuration.

3. COGNITIVE CYCLE

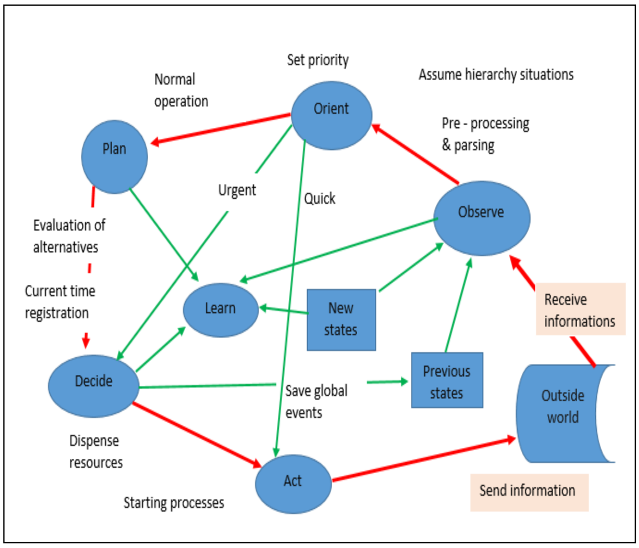

Fig 3: Cognitive Cycle

A cognitive entity is formed from an ideal Cognitive Radio (iCR) which can sense, perceive, orient, plan, decide, act and learn in real time. Cognition cycle implements the capabilities of iCR in a reactive sequence. The outside world provides stimuli, which enters the CR as sensory interrupt, and is send to cognitive cycle for a response. iCR observe the environment and decide the action by using features of learning and reconfiguring software Defined Radio parameters. There are four period of cognition cycle- Wake, Sleep, Dream and Prayer period. In wake period, initial activities are carried out i.e. observation and reaction to the environment which constitutes large period of time. Sleep period is for the power down condition. Computational and machine learning algorithm is performed in dream period. Prayer period means interacting with higher command such as network infrastructure regarding modification of parameters [7], [11].

During wake period, new stimulus is accepted on any of CRs sensor or new primary cognition cycle is commenced when previous one is completed. The environment is observed by CR by resolving and understanding each component of incoming information. In observation phase, a CR also read temperature, light level sensors to figure out user's communication context.

Ideally, a cognitive network should predict the environment conditions and adjust the problem before they occur; this intelligence is the only feature which is making CR different from conventional radios. Additionally, architecture of a Cognitive network should be extensible and flexible, supporting future improvement, network elements and goals [5].

Observe (Sense & Perceive): The iCR accepts multiple stimuli in different dimensions simultaneously to scan and discover the environment and by combining these stimuli using past experience it generate the plan for achieving required goal. Thus iCR summarize experience and perform comparison of prior and current stimuli. A CR may aggregate experience by remembering events, which is based on learning and computational architecture for rapidly correlating current experience against prior experience. To identify new stimuli, novelty detector is used. The observe phase consist of 1) User Sensory and perception 2) Environment (RF and physical both) sensor subsystem.

Orient: There are six components in Cognitive radio architecture (user SP, Environment, SDR, System application and cognition); the orient phase is included in the cognition component of Cognitive radio architecture. This orient phase find importance of an observation by combining the observation to prior known set of stimuli of scene. It consists of Short Term Memory (STM) to store information for less time and Long Term Memory (LTM) to store information over long time. Matching of current stimuli to stored experience may be achieved by stimulus recognition or by binding. The orient phase is the first collection of activity in the cognition component.

Stimulus Recognition: There should be an exact match between prior experience and the current stimulus, for the possibility of stimulus recognition. These exact matches are continuously monitored and recorded by CR. The response to a given stimulus, by default is to repeat that stimulus to the next layer up the inference hierarchy for aggregation of the raw stimuli. Sometimes, an immediate action is initiated which is called as reactive stimulus response behavior. A power failure will directly start an act that saves the data (In act phase, there is an immediate path for this). An urgent path is shown in case of loss of signal which requires reallocation of resources.

Binding: Binding takes place, when the current stimulus and prior experience are nearly matched and a strategy is found for applying prior experience to the current stimulus. For example some features of the current stimuli is unmatched with prior experience, then binding provides a plan for similar behavior of stimuli as compared with prior experience.

Plan: Planning take place in plan phase of cognition cycle which includes reasoning about time. Open source planning tools and formal models of causality are used for inducing planning subsystem into Cognitive Radio architecture. Such tools enable the synthesis of RF and information access behavior in a goal oriented way based on perception from the visual, audio , text and RF domain.

Decide: The decide phase selects among the candidates plans. The channel is selected based on user requirement and quality of service. There should be no interference once the decision is taken for allowing the access of channel.

Act: The selected process is started in act phase of cognition cycle, using effector module of Cognitive Radio Architecture (CRA). This effector module may access the external world or CR's internal states.

Learning: Learning includes internal model and integrate machine learning algorithm into iCR. It is a function of perception, observation, decision and actions. Internally generated model is compared with new type of model which is in response to an action.

Each iteration of the cognition cycle must take a specified amount of time. A sleep period is a long time during which the radio is not in use, but has enough power for processing. During this period machine learning algorithm can be executed without affecting its ability to support user requirement [11].

4. FUNCTIONS

4.1 Spectrum Sensing:

CR allows unlicensed user to access licensed spectrum band when the primary user is absent. To check the primary user transmission CR scans the spectrum and identify unoccupied frequency spectrum or white spaces without interfering primary user. This operation is called spectrum sensing.

Spectrum sensing can be performed in two ways: Proactive or reactive. In proactive sensing, spectrum is periodically monitored and record is maintained. So before starting with transmission, every time a database is checked which stores all the spectrum sensing information whereas in reactive sensing, on demand spectrum sensing takes place [5]

4.2 Spectrum decision:

After the identification of spectrum holes, CR should analyze the available frequency band and decide which band is best among the available spectrum band according to the requirement of user [5].

4.3 Spectrum Sharing:

Multiple users are trying to access the spectrum at the same time; therefore network coordination is required to avoid collision between spectrums [4]

4.4 Spectrum mobility:

Secondary user should vacate the spectrum band when the primary user arrives and search for another spectrum band to continue its transmission. This switching between spectrum bands is called spectrum mobility. It is still an open and challenging issue because there should not be any delay between spectrum handoff. No suitable models are proposed for reducing the latency between switching [6].

5. ARCHITECTURE

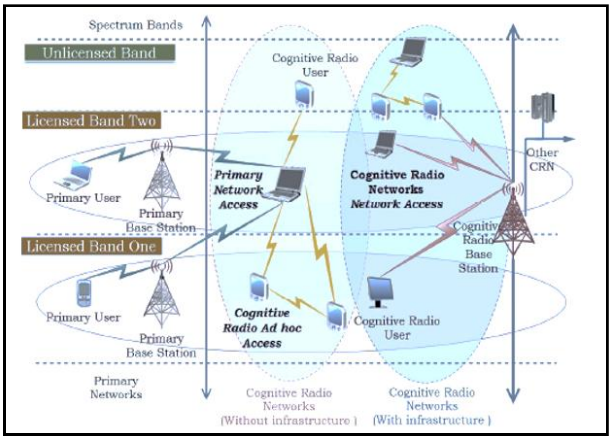

Fig 4: Cognitive Radio Architecture [7]

The architecture of CR is divided into

1) Infrastructure

2) Sharing of spectrum

3) Type of network

4) Access type

According to infrastructure, there are two types of CR, Centralized and distributed network architecture.

In Centralized network architecture, there is a central controller which coordinates and controls the allocation of resources to secondary users or cognitive users. All the decision of spectrum allocation and spectrum mobility is taken by this centralized controller. Whereas, In distributed or adhoc architectures, Individual nodes sense the spectrum and make their own decision about spectrum access strategy based on observing locally on the spectrum dynamics.

According to sharing, there are two types Cooperative and Non cooperative sharing

In Cooperative spectrum sharing, secondary users sense the spectrum and share the sensing information with the other users and take spectrum access decision cooperatively. In non-cooperative spectrum sharing, users individually sense the spectrum and take their own decision. Every user is maximizing its own benefit and no sharing of information takes place [4].

According to type of network, there are primary and cognitive network

Primary network also called licensed network consist of a set of primary users and a primary base station. Primary user has exclusive right to the spectrum and cognitive users are not allowed to disturb the primary user transmission. Cognitive network also called unlicensed network consist of a set of secondary users with cognitive base station. The spectrum allocation of cognitive users is controlled by cognitive base station which act as a hub of secondary network .These secondary users and base station are allotted with the capabilities like sensing, decision making, and learning for spectrum access. If many secondary users are sharing common spectrum band, then their spectrum usage can be managed by a central entity called spectrum broker. The spectrum broker accepts the request of secondary users and provide with required resources for efficient spectrum utilization [7].

According to access, there are two types, spectrum underlay and spectrum overlay.

In spectrum underlay, cognitive or secondary users are transmitting their data below the inference limit, where primary users are not taking part in transmission. Interference temperature limit is imposed on SU transmission. Therefore secondary user is not performing spectrum sensing. In spectrum overlay, secondary user can access the spectrum band when primary user is inactive. So there is no interference temperature limit imposed on secondary user's transmission. SU have to detect the presence of primary users to initiate their transmission [7]

6. SECURITY

Due to dynamic nature of CR, it is more vulnerable to attacks as compared with the traditional wireless system which is based on fixed spectrum allocation. According to FCC rule, there should be no modification to the primary user's transmission. So the techniques implemented to detect and mitigate the attacks in CR, cannot allow interaction between primary and secondary users. There are various techniques in existing literature for detection and removal of attacks in CR taking place at different layers of OSI model [12].

Physical layer is the lowest and crucial layer which provides an interface to all the upper layers. The operation of CR network is based on sensing and switching of spectrum depending on environment conditions. Thus signals are transmitted and received on different frequencies across wide frequency spectrum which makes the operation of physical layer more cumbersome. Spectrum sensing is the fundamental operation of Physical layer which affected by a dangerous attack called Primary User Emulation (PUE) attack. In this attack, an attacker copies the characteristics of primary user and arrives to access the spectrum. This forces secondary user to leave the channel so that there is no interference to the primary user. As Spectrum Sensing is the basic operation of CR, this PUE attack detection is the biggest challenge for smooth transmission and efficient channel utilization. The first work done by chen et al to detect PUE attack [16] was based on location verification. Trusted location verifiers were used which consist of a primary user location database. Then this stored database is compared with the received primary signals. If it does not match, the suspect is considered as an attacker. Objective Function attack is also a physical layer attack. This attack creates problem in cognitive Engine of CR which consists of the entire learning algorithm and the core element which makes CR an Intelligent Radio [12].

Cognitive radio is called smart radio because it senses the surrounding environment; modify its parameters such as bandwidth, transmission power, coding, protocols, frequency of operation, and packet size. This radio parameters adjustment is performed by the cognitive engine inside the CR. When these parameters are modified by the Cognitive Engine after solving objective functions, an attacker can manipulate the parameters so that the result is according to attacker's requirement. Additionally, these attacks affect the learning algorithm that use objective functions and force radios to believe that some frequencies, modulation types or bandwidth are less optimal and should be avoided. Till now, no good techniques are available to mitigate this attack [14].

Another physical layer attack is jamming attack. In this attack, a malicious user send continuous packet of information so that the spectrum seems busy to the other secondary users. Next layer is the link layer, above the physical layer. The key function of this layer is to ensure reliable transmission of packet from source node to destination node. The major attack which takes place at link as well as physical layer is called spectrum sensing data falsification attack (byzantine attack). There are two ways of performing spectrum sensing in CR: Centralized and distributed spectrum sensing. In Centralized Spectrum Sensing, there exist a fusion centers which collect the result of spectrum sensing of all the secondary users and then make decision whether primary user is present or absent. In distributed spectrum sensing, individual secondary user senses the spectrum and sends the information to the neighbor and they cooperatively decide on spectrum availability [12], [13].

Byzantine attack takes place when some malicious user provides wrong spectrum sensing result to the neighbor or fusion central i.e. central controller This attack result in wrong spectrum sensing decision, disruption to primary users and delay in transmission of information. After the spectrum sensing, path is determined to deliver the packets to the destination [12]. An attacker can modify the routing path by giving wrong information to the honest node which transfers the packet traffic from the corrupted path. Table 2. Explains all the attacks taking place at different layer of OSI model

7. OPEN CHALLENGES

7.1 Quality of service

Spectrum mobility should be carried out with negligible latency. To reduce delay and loss of information during spectrum handoff, new mobility methods is required to be designed. Due to spectrum handoff in CR network link state parameters are affected which leads to network instability problem - clogging or link error. Therefore, maintaining service quality for the complete cognitive operation is still an ongoing issue [4].

7.2 Spectrum sensing techniques

Spectrum sensing algorithm implemented till now is Energy detection, Match filter detection and Cyclostationary feature detection. In matched filter detection, primary user location has to be known in advance and also many assumptions are required, which is very difficult to implement practically. Also, these techniques give less accurate result which fails in certain conditions.

7.3 Complex Circuitry

For reliable detection of primary user transmission, a complex circuit is needed for analog to digital converter to sample wideband signal with large dynamic range. It becomes difficult to balance between high speed and high accuracy; therefore it is important to decrease the dynamic signal range before analog to digital conversion [3]

7.4 Security

Network security has become a major issue and also open challenge in Cognitive Radio network. There are various attacks in CRN as described in the previous section. The major attack which affects spectrum sensing operation is Primary User Emulation (PUE) attack. A stationary as well as mobile primary user suffers from this attack. Stationary primary users are TV bands and cellular network whereas mobile primary users are wireless microphone. There are various techniques for detection of PUE attack for stationary primary users. But for mobile primary user, only two techniques by author chen [15] are implemented. Thus, there is a need of a technique which can detect PUE attack for both stationary as well as mobile primary users.

7.5 Sensing period

Two periods exist in cognitive user transmission process: Sense and quiet period. Sensing cannot be performed while transmitting packets Hence CR users should stop transmitting while sensing which decreases spectrum efficiency. It becomes difficult to maintain a balance between sensing accuracy and spectrum efficiency.

7.6 Energy Consumption

Energy efficiency is major concern in wireless communication as it presents battery life. In Cognitive Radio lot of time is consumed for spectrum sensing Operation. To improve energy consumption without any compromise with the spectrum sensing operation, quality of service and seamless communication is a topic of interest.

Table 2. Attacks in CR

Sr.No.	ATTACKS	LAYER	DESCRIPTION
1	Primary User Emulation (PUE) Attack	Physical	A malicious user mimics the signal characteristics (modulation type, carrier frequency, transmission power) of primary user and this makes secondary user believe that primary user has arrived and vacate the channel [16]
2	Objective Function Attack	physical	Cognitive engine consist of learning process and attacker try to attack through manipulation of cognitive radio parameters. If these parameters are manipulated , then learning capability of CR is affected badly [13]
3	Jamming	Physical	Attacker unnecessarily send packet of data on the channel and make secondary user believe that channel is occupied.
4	Spectrum Sensing Falsification Attacks	Link	Also called Byzantine attack ,it takes place when a malicious user send wrong spectrum sensing result to its neighbor or to fusion center, which lead to false alarm and degradation of performance [13], [17]
5	Control channel saturation Denial of Service attack	Link	When multiple secondary user want to transmit at the same time, common control channel becomes a problem as the channel can support only a limited number of data channels. An attacker generate fake MAC control frames for keeping channel busy and therefore reducing performance of network and increase
6	Selfish Channel negotiation	Link	In multihop environment, secondary user sometimes refuse to send the data to other host to save its energy and increase its own throughput [12]
7	Hello flood attack	Network	In this attack, a malicious user send a broadcast message to all the other nodes that it is their neighbor and then all the data will be routed through this path which is corrupted [12], [18]
8	Sinkhole	Network	In this attack, an attacker claims the best way to send the packet to the destination. This attack is more serious in infrastructure base network as all information is passed through base station which allows the malicious user to falsely claim that it is the best route got forwarding the packet [18]
9	Lion attack	Transport	It is cross layer attack performed at basically physical link layer and targeted at the transport layer where imitating a primary user transmission will force a CRN to perform frequency handoffs and thus degrading TCP performance [12], [13]

8. CONCLUSION

This paper outlines the definition and incitement of Cognitive radio Technology, as well as presented the background knowledge and advances of cognitive radios. A brief overview on security threats, including physical, link, network and transport layer attacks is presented Finally issues in cognitive Radio which needs further development are highlighted. The major challenge till now is need of a technique which can avoid interference to stationary as well as mobile primary users. Also seamless communication during the spectrum mobility stage needs further development. The research on cognitive radio is still on its earlier stage. Thus its other entire area is required to be explored for smooth and secure operation of upcoming next generation system.

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